The Double Chooz Experiment

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Abstract.
The Double Chooz reactor neutrino experiment aims at observing the last neutrino oscillation not yet observed and at measuring the corresponding mixing angle θ_{13}. A relatively big value of this angle will allow the measurement of CP violation in the leptonic sector by the next neutrino oscillation experiments. This disappearance experiment will precisely count the number of anti–neutrinos produced by the two nuclear reactors of the Chooz nuclear plant in France. In a first stage, Double Chooz will only use a far detector which could allow to give a $\sin^2(2\theta_{13})$ low limit of 0.06. Two years after, a near detector, identical to the far one, will be in operation and allow us to push this limit down to 0.03 by reducing the systematic errors. The status of this experiment is presented in this paper.

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INTRODUCTION

The neutrino oscillations and consequently the fact that the neutrinos have mass, is now well established. The oscillation parameters, two independent squared mass differences Δm^2_{ij}, three mixing angles θ_{ij} and a CP violation phase δ_{CP} (in case of Majorana particles two more phases have to be added) describe the whole phenomenon for neutrinos propagating in vacuum. The two squared mass differences and the two over three mixing angles are already measured with a relatively good accuracy. The sign of Δm^2_{23} is not yet known, inducing a mass hierarchy (normal or inverted) uncertainty. One of the three mixing angles, θ_{13}, is not yet known and only an upper limit exists mainly extracted by the neutrino reactor experiment CHOOZ [1]. Recent values of the oscillation parameters can be found in [2]. In this last paper, the latest hints about a non–zero θ_{13} are given.

The reactor neutrino oscillation experiments under preparation, Double Chooz [3], Daya Bay [4] and RENO [5], will try to observe a disappearance of $tracks\nu_e$'s produced in the cores of the corresponding nuclear plants and thus measure θ_{13} or at least give a limit on it. This limit would help to well define the future neutrino oscillation projects mainly using high intensity neutrino beams produced by accelerators.

An improved version of the first CHOOZ experiment detector will be used by the Double Chooz Collaboration, using also in a second stage, a near detector to significantly improve the physics performance.

[1] on behalf of the Double Chooz Collaboration

DESCRIPTION OF THE EXPERIMENT

Nuclear reactors are very intense sources of $\bar{\nu}_e$'s emitted mainly by the fission of fuel elements (^{238}U, ^{235}U, ^{239}Pu and ^{241}Pu). Each fission liberates an energy of 200 MeV and generates 6 $\bar{\nu}_e$'s. The 2 Chooz reactors, 4.27 GW thermal power each, emit about 1.7×10^{21} $\bar{\nu}_e$'s/s. The mean neutrino energy is of the order of 4 MeV and the energy spectrum varies from 1.8 MeV to about 8 MeV. Due to the low energy range of the emitted neutrinos, only disappearance measurements can be performed.

The far detector is placed at a distance of $\sim$1050 m, near the first maximum disappearance probability of $\bar{\nu}_e$'s produced by the nuclear cores. Fig. 1 presents the neutrino survival probability as a function of the distance from their production point for three neutrino energies ($\Delta m^2_{21} = 7.59 \times 10^{-5}$ eV^2, $\Delta m^2_{31} = 2.46 \times 10^{-3}$ eV^2, $\theta_{12} = 34.4°$, $\theta_{23} = 42.8°$). The near detector, essential to monitor the reactors' operation, is placed at a distance of $\sim$400 m, where the disappearance probability is still small.

Reactor antineutrinos are detected through the inverse beta decay $\bar{\nu}_e + p \rightarrow n + e^+$. The signature of a neutrino interaction is the coincidence of a prompt 2γ signal induced by the positron annihilation with a matter electron and a delayed signal ($\Delta t \sim 30$ μs) from the neutron capture. For the detection of these signals, Double Chooz uses a liquid scintillator loaded with Gadolinium to increase the neutron capture cross section and the released energy (7–8 MeV).

The signature of a neutrino interaction can be mimicked mainly by two kinds of background events, the accidental and correlated signals. The accidental background corresponds to the coincidence of a positron–like signal coming from natural radioactivity of the sur-

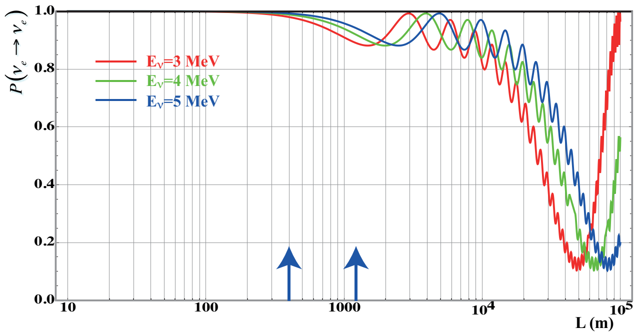

FIGURE 1. Oscillation probability versus distance assuming $\theta_{13} = 10°$ (the arrows indicate the positions of the near and far detectors).

rounding environment, with a neutron induced by cosmic muon spallation in the surrounding rock and captured in the detector. The correlated background are events that mimic both parts of the coincidence signal. They come either from fast neutrons induced by cosmic muons, which can produce proton–recoils in the target scintillator (misidentified as e^+) and then are captured after thermalisation, or from the β–n decay of long–live cosmogenic radioisotopes (^{9}Li, ^{8}He) produced by muon interactions in the scintillator.

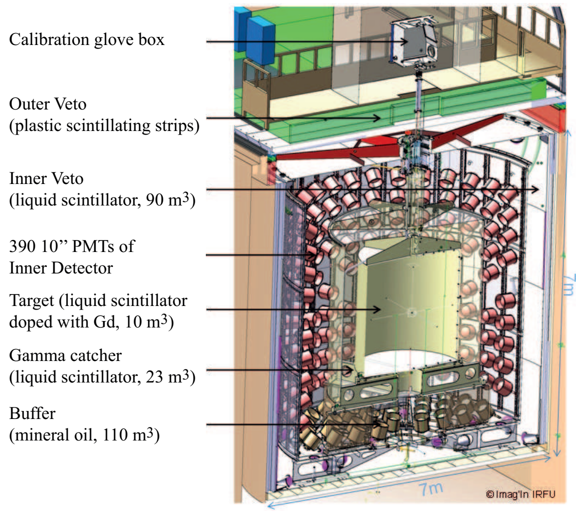

FIGURE 2. The Double Chooz detector.

THE DETECTOR

The far detector is located in an underground laboratory (at the same location than the detector of the first CHOOZ experiment) providing a 300 m.w.e. shielding. The near detector, identical to the far one, will be located in a tunnel under a small natural hill (overburden 115 m.w.e.).

Fig. 2 presents a schematic view of the detector. Going from inside to outside, one can distinguish the target where the detectable neutrino interactions occur composed by an acrylic transparent tank containing 10 tons of liquid scintillator doped with 0.1% Gadolinium. The target is enveloped by the γ–catcher, a concentric acrylic cylinder (liquid scintillator, 55 cm thick), to detect γ–rays produced by the neutrino interactions and escaping the target. This volume is the main difference with the first CHOOZ experiment detector.

The volume between the γ–catcher and the stainless steel cylinder of the inner detector (buffer zone, 105 cm thick) is filled with mineral oil protecting the target from the PMT radioactivity, reducing considerably the accidental background. The 390 10" Hamamatsu PMT's detecting the light coming out of the scintillating volumes are fixed on the inner veto wall. They provide about 13% coverage.

In the outside part of the cylinder (outer detector), a cosmic veto using a liquid scintillator (50 cm thick) and 78 8" PMT's helps to reject cosmic rays. The whole detector is surrounded by an iron shield, 15 cm thick, protecting the detector from the rock radioactivity. To reinforce the cosmic rejection, a second veto is used. It is placed on top of the detector and made of scintillating strips readout by multianode PMT's.

Calibration systems will be deployed periodically into the target and the γ–catcher allowing us to check the stability of the system. A glove box interface with an associated clean room installed on the top of the detector will allow the deployment of radioactive sources for energy calibration. Light injection systems using optical fibers and LED's are installed in the inner and outer detector to monitor the behavior of all PMT's.

The PMT signals arrive at high voltage splitters through 25 m length cables. From the splitters, 30 m cables are used to bring the signals to the front end electronics amplifying them by a factor of ~ 7. Their wave-

TABLE 1. Systematic uncertainties in CHOOZ and Double Chooz reactor experiments.

Parameter	CHOOZ	Double Chooz
reactor fuel cross section	1.9%	-
reactor power	0.7%	-
energy per fission	0.6%	-
number of protons	0.8%	0.2%
detection efficiency	1.5%	0.5%
Total	2.7%	0.6%

forms are recorded by 8–bit Flash ADC digitizers. All electronics are located in the electronics hut at the end of the lab.

EXPERIMENT PERFORMANCE

The main systematic uncertainties, compared to the first CHOOZ experiment, will be significantly reduced by having both near and far detectors. Table 1 summarizes the systematic uncertainties in the measurement of the antineutrino flux comparing both the CHOOZ and Double Chooz detectors.

An uncertainty from the neutrino contribution of spent fuel pools remains but at a negligible level for Double Chooz. An important parameter is the number of free protons inside the target volume determining the neutrino detection rate. A very precise target weighing procedure during detector filling with a precision of 0.2% has been constructed.

The optimization of the Double Chooz detector design allows us to reduce the detection efficiency systematic errors to the level of 0.5% while keeping high statistics. The dominant detector related systematic error is expected to be kept below 0.6%.

The selection of radioactive pure materials for the detector construction and the passive shielding around the active region considerably reduce the accidental background events. The cosmic veto systems will help to reject the correlated background events.

The total background rate is estimated to be 1–2 events per day in the far detector to be compared with a neutrino rate of about 45 per day. The error induced by the background subtraction in both detectors is expected to be less than 1%.

Fig. 3 presents the Double Chooz θ_{13} sensitivity versus the time in years. In phase I where only the far detector will be operated, after 1.5 years a $\sin^2(2\theta_{13})$ limit of 0.06 will be reached, while in phase II, with both detectors in operation, a limit of the order of 0.03 will be reached after 4 years from the beginning of the experiment. It has to be noted that some recent hints ([2]) indicate that $\sin^2(2\theta_{13})$ could be as large as 0.04, in reach by Double Chooz experiment.

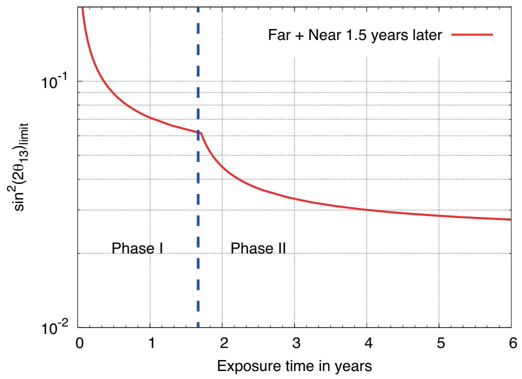

FIGURE 3. $\sin^2(2\theta_{13})$ sensitivity limit for the detectors installation scheduled scenario.

CURRENT STATUS

The Double Chooz experiment is now at the end of the installation phase of the far detector. At the end of 2010, the whole far detector was successfully filled with all liquids and the upper shielding was installed. The acquisition system is fully installed and under commissioning. Runs have already been performed with and without liquid using several acquisition configurations. Beginning 2011, Double Chooz will be able to detect the first neutrinos coming from the two nuclear reactors.

In February 2011 the glove box allowing the radioactive sources deployment will be installed. After the installation of the glove box, the outer veto system, already produced, will also be installed marking the end of the far Double Chooz detector installation.

The excavations for the near detector will start in Spring 2011 and the near detector lab is expected to be ready by the end of 2011. At the end of this period, the installation of the near detector will start and will last about 30 weeks. It is thus expected that both, far and near detectors, will be simultaneously operational in Autumn 2012.

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